Design of Edge Computing System for Photovoltaic Panel Hot Spot Detection Based on Machine Learning

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Abstract. The hot spot effect of photovoltaic panel refers to the local heating phenomenon caused by the photovoltaic panel being covered, which not only seriously affects the power generation efficiency of photovoltaic panel, but also is one of the most important factors threatening the service life of photovoltaic panel. In this paper, an edge computing system was designed to detect hot spot effect based on real-time sensing data such as current, voltage and illuminance. The system consists of three parts: data acquisition side, data processing side and data display side. The hot spot detection algorithm model based on machine learning is deployed on the edge side, which can detect the degree of hot spot effect and locate the hot spot according to the sensor data of each photovoltaic panel in real time. Additionally, this system could push the data to the cloud management platform and each user terminal to realize remote operation and maintenance.

1. Introduction

As a renewable and clean energy source [1], photovoltaic energy has gradually become an important alternative to traditional energy sources to achieve the "carbon neutral" and "carbon peaking" goals [2]. During the use of photovoltaic panels, the panel defects caused by various environmental factors will directly affect the power generation efficiency [3]. The most common and most harmful is the hot spot effect of photovoltaic panels. Hot spot effect refers to the heat generation phenomenon caused by the partial shading of the photovoltaic module [4]. The severity of the hot spot effect varies and affects the working performance of photovoltaic panels differently. At present, the detection for hot spot effect generally adopts aerial photography inspection by unmanned aerial vehicle equipped with thermal radiation infrared imager, which transforms the invisible infrared energy emitted by objects into visible thermal images [5], sends the captured infrared images of photovoltaic panels to the background, and identifies and locates hot spot panels by manual analysis. The method is inefficient, not real-time, and the unmanned aerial vehicle work is vulnerable to weather [6]. In this paper, we design and implement a machine learning based edge computing system for hot spot detection of photovoltaic panels. The system contains hardware facilities such as sensors, edge computing motherboards and user terminals, as well as software such as signal processing, algorithmic models and user interaction. The system will input the real-time current, voltage and illumination data collected by the sensors of photovoltaic panel array into the algorithm model, calculate the degree of hot spot effect of the photovoltaic panel, and push the data to the server of the cloud management platform, and a variety of user terminals can download the information for the degree of hot spot effect on the photovoltaic panel from the above platform to realize remote operation and maintenance.

2. Hardware design of the system

2.1. System Composition

The system consists of three parts: data acquisition side, data processing side and data display side (Figure 1). The data acquisition side mainly consists of sensors installed on each photovoltaic panel, including voltage sensors, current sensors and illuminance sensors, which are used to collect voltage, current and illuminance data from the photovoltaic panels. Data processing side including Raspberry Pi computer, 5G data transmission module and power supply module for receiving, processing and sending data. The data display side includes two parts: remote wireless terminal and touch screen for information display and user interaction. The system uploads data to the cloud management platform in real time through the 5G data transmission module, and the remote wireless terminal downloads real-time data from the cloud management platform through the network to realize the functions of on-site dynamic real-time data monitoring, remote interactive setting of working parameters, and graded pushing of early warning information.

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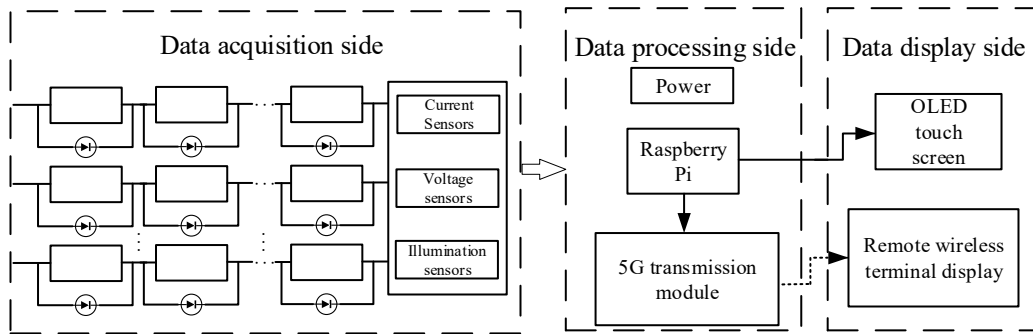 Address: [1] Huadian Rd., Hangzhou, Zhejiang, 310012, China

Fig. 1: System architecture diagram. The solid arrow indicates a wired connection and the dashed arrow indicates a wireless connection.

2.2. System hardware selection

To meet the computing requirements of the system, Raspberry Pi 3B (1GB memory, 1.2GHz quad-core processor) is used as the main control module. In terms of data display and user interaction, a 10-inch HD OLED touch screen is used. A 5G module development board equipped with a USB adapter board and NGFF (M.2) interface is employed in the system to achieve remote data transmission.

2.3. System deployment and connectivity

The data acquisition side is deployed on the photovoltaic panel modules. Among them, the illuminance sensor is deployed on the surface of the photovoltaic panel, and the voltage sensor and current sensor are deployed in the output circuit of each panel. The data acquisition side and data processing side are connected through RS232 serial port, the power supply module in the data processing side provides 5V/2A voltage and current for Raspberry Pi and touch screen, and the 5G transmission module is directly connected to Raspberry Pi through USB. The data display side of the touch screen is connected to the Raspberry Pi via HDMI, and the remote wireless terminal communicates with the Raspberry Pi indirectly through the remote server of the cloud management platform.

3. Software design of the system

3.1. Software Design for Edge Computing

Edge computing technology is a kind of decentralized computing, which is a distributed open platform that integrates the core capabilities of network, computing, storage and application, and provides edge intelligent services at the edge of the network near the source of things or data [7~8]. In this paper, sensors and terminals are connected through various IoT interfaces (IP-based PLC/RF/RS485/RS232, etc.) supported by the edge computing gateway to achieve terminal device access. Before the algorithm model calculation, the system performs pre-processing such as smoothing and noise reduction on the real-time data collected from the sensors to improve the robustness of the system. The pre-processed data is input to the algorithm model for

inference to derive the hot spot effect degree value. The system detects all panels in the photovoltaic panel array, obtains the hot spot effect degree data for all panels, and displays them on the touch screen. In addition, the system sends the photovoltaic panel sensor data and hot spot effect data monitored in real time to the remote server of the cloud management platform via a 5G network module.

3.2. Touchscreen software design

The touch screen software is developed with Java programming language and contains a welcome screen and a main screen (Figure 2). The welcome screen displays the power-on screen and device information. The main interface displays information on the location, irradiance, output current, output voltage and output power of each photovoltaic panel string and module, as well as interactive functions such as global, string and module classification alarm threshold settings. Users can click the start button to locate the intelligent hot spot panel components and output various degree alarm signals.

Fig. 2: Touchscreen main interface

3.3. Software design of wireless terminal

To realize remote monitoring of the degree of hot spot effect of photovoltaic panels, the edge computing system uploads panel data and hot spot data to the cloud management platform for data management and storage in real time through the 5G network module and the agreed interface specification. At the same time, to facilitate users to access and call data anytime and anywhere, a mobile application running on Android system (Figure 3) is designed and developed to download sensor data and

alarm information of photovoltaic panels from the cloud management platform in real time, and to realize remote interaction with multiple users through indirect communication with the edge computing system.
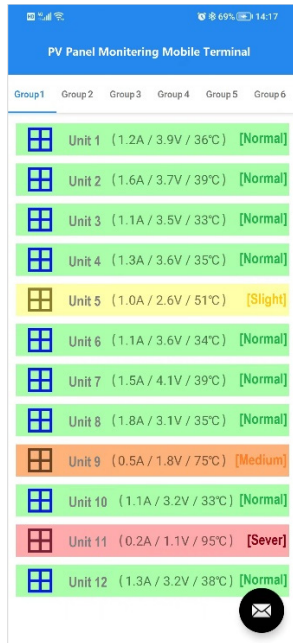

Fig. 3: Photovoltaic panel hot spot monitoring system APP interface

4.Hot spot detection algorithm design

4.1. Algorithm model design

The hot spot detection algorithm is based on a multilayer perceptron model with an error back propagation algorithm for adjusting the weights of each node. The model contains 3 layers of neurons in the input layer, hidden layer and output layer (Figure 4). The input layer contains 3 neurons, which receive voltage, current and illumination data, respectively. The hidden layer contains 16 neurons and uses Relu as the activation function for the nonlinear representation of the data. The output layer contains 1 neuron and uses Sigmoid as the activation function to output a hot spot degree value between 0 and 1.
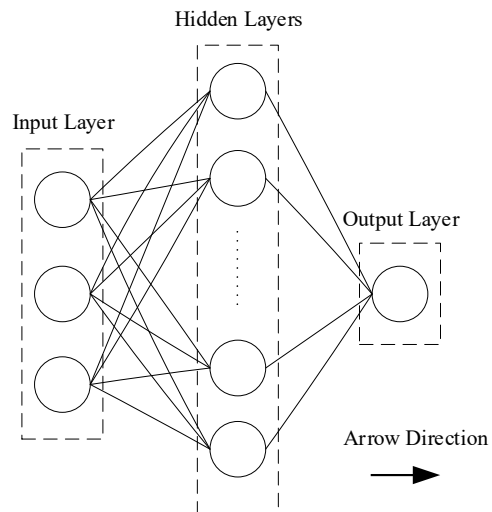

Fig. 4: Three layers of neurons

4.2.Algorithm model training

The data set used for model training contains 2000 simulation data samples, where the input values $X=[x1,x2,x3]$ are voltage, current and illumination respectively, and the expected value $Y \in [0,1]$ is the value of the labeled hot spot degree. A 5-fold cross-validation method was used to slice into the training set, validation set and test set. The z-score transformation was performed before data input to eliminate the effect of magnitude. The root mean square error (RMSE) was used as the loss function, and after about 1000 iterations, the RMSE of the training set approached 0.00001, and the RMSE of the validation set was reduced to the minimum set value of 0.01 to obtain the regression model, and the RMSE of 0.016 was obtained by inputting the test set data to meet the application requirements.

5.System Testing & Analysis

To verify the feasibility and effectiveness of the system, tests were conducted based on some of the current, voltage and illumination test data provided. The interactive interface shows the addresses of photovoltaic panel strings and modules, and different colors of green, yellow, orange and red indicate different degrees of hot spot effect of modules with normal, mild, moderate and severe, while output current, output voltage, output power and solar irradiation data of each module are displayed (Figure 5). After the test, the severity of hot spot effect of modules 01, 02, 04 and 08 in string 1 was detected as normal, normal, moderate and mild, which is consistent with the judgment result of manual detection using infrared thermal imaging camera.
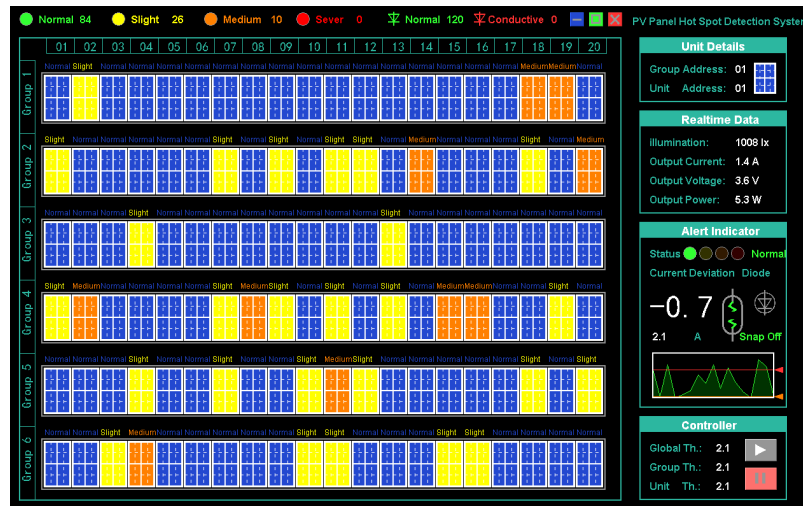
Fig. 5: Hot spot identification test effect

6.Conclusion

This paper designs a machine learning-based edge computing system for photovoltaic panel hot spot detection from the current practical requirements of photovoltaic panel hot spot effect detection. The system adopts a system architecture consisting of data acquisition side, data processing side and data display side, and makes a detailed design for hardware selection, data processing and display side function implementation. The system is verified by actual production data testing, and it meets the requirements of photovoltaic panel hot spot effect monitoring and early warning. The system combines the sensor data of photovoltaic panels and constructs the hot spot detection model by machine learning method, thus realizing intelligent hot spot detection and overcoming the difficulties of traditional detection methods which are not strong in real time and easily affected by weather, and has high application value.

Acknowledgements

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